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INTERNATIONAL APPLICATION NO.  
PCT/FR00/00917 ✓INTERNATIONAL FILING DATE  
11 APRIL 2000 ✓

PRIORITY DATE CLAIMED

15 APRIL 1999 ✓

TITLE OF INVENTION

TWO-DIMENSIONAL DETECTOR OF IONIZING RADIATION AND PROCESS FOR MANUFACTURING THIS DETECTOR

APPLICANT(S) FOR DO/EO/US

Jean-Louis GERSTENMAYER

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (24) indicated below.
4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
  - a. ☐ is attached hereto (required only if not communicated by the International Bureau).
  - b. ☒ has been communicated by the International Bureau.
  - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
  - a. ☒ is attached hereto.
  - b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
  - a. ☐ are attached hereto (required only if not communicated by the International Bureau).
  - b. ☐ have been communicated by the International Bureau.
  - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
  - d. ☒ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☒ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☒ A copy of the International Search Report (PCT/ISA/210).

## Items 13 to 20 below concern document(s) or information included:

13. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22. ☐ Certificate of Mailing by Express Mail
23. ☒ Other items or information:

Notice of Priority, Drawings (3 sheets)

PCT/IB/304, PCT/IB/308

Amended Sheets 1 and 1a

Request for Consideration of Documents Cited in the International Search Report

Page 2 of 2

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IN THE UNITED STATES PATENT & TRADEMARK OFFICE

IN RE APPLICATION OF :

JEAN-LOUIS GERSTENIMAYER : ATTN: APPLICATION DIVISION

SERIAL NO: NEW U.S. PCT APPLN :  
(Based on PCT/FR00/00917)

FILED: HEREWITH :

FOR: TWO-DIMENSIONAL DETECTOR :  
OF IONIZING RADIATION AND  
PROCESS FOR MANUFACTURING :

PRELIMINARY AMENDMENT

ASSISTANT COMMISSIONER FOR PATENTS  
WASHINGTON, D.C. 20231

SIR:

Prior to a first examination on the merits, please amend the above-identified  
application as follows:

IN THE CLAIMS

Please cancel Claims 1-11 without prejudice.

Please add new Claims 12-22 as follows:

12. (New) Two-dimensional detector of incident ionizing radiation composed of first  
particles, comprising:

a stack of sheets of a first material configured to emit second particles by interaction  
with the incident ionizing radiation;

layers of a semiconducting material that alternate with the sheets of the first material and that may be ionized by the second particles, each of the layers being associated with one of the sheets, the stack having opposite first and second faces each including corresponding edges of the sheets and layers, the detector configured to be laid out such that the ionizing radiation arrives on the first face, a length of each sheet measured from the first face as far as the second face being equal to at least one tenth of a free average path of the first particles in the first material;

groups of parallel and electrically conducting tracks extending from the first face to the second face parallel to the layers, each group being associated with one of the layers and in contact with an associated layer, the tracks being designed to collect charge carriers that are generated in the layers by interaction of the layers with at least one of the second particles and the first particles and that are representative of the first particles in intensity and in position; and

means for creating an electric field capable of causing collection of charge carriers through the tracks.

13. (New) Detector according to claim 12, wherein the first material is electrically conducting, the tracks are electrically insulated from the sheets, and the means for creating the electric field comprises means for applying a voltage between the tracks and the sheets, this voltage able to cause the collection of charge carriers through the tracks.

14. (New) Detector according to claim 12, wherein each group of tracks is fully located within the layer with which it is associated.

15. (New) Detector according to claim 14, wherein the first material is electrically conducting and the means for creating the electric field comprises means for applying a

voltage between the tracks and the sheets, this voltage able to cause the collection of charge carriers through the tracks.

16. (New) Detector according to claim 12, wherein the sheets are electrically insulating, an electrically conducting layer is inserted between each layer of semiconducting material and the sheet that is associated with it, and the means for creating the electric field comprises means for applying a voltage between the tracks and the electrically conducting layers, this voltage able to cause the collection of charge carriers through the tracks.

17. (New) Detector according to claim 12, wherein the semiconducting material is selected from the group consisting of thin layers of diamond, CdTe, ZnTe, CdZnTe, AsGa and their alloys, InP, InSb, SiC, crystalline silicon, amorphous silicon, organic crystals, amorphous selenium, and chalcogenic glass ( $\text{As}_2\text{S}_3$ ).

18. (New) Detector according to claim 12, further comprising an electronic device configured to read electrical signals output by tracks when the tracks collect charge carriers.

19. (New) Detector according to claim 18, wherein one end of each track is curved to extend onto an edge of the corresponding layer of semiconducting material, this edge being located on the second face of the stack, and further comprising electrically conducting pads that are in contact with the corresponding curved ends of the tracks.

20. (New) Process for manufacturing the detector according to claim 12, wherein a layer of semiconducting material is formed on each sheet, this layer being provided with the group of tracks associated with it, and the sheets provided with layers of semiconducting material and tracks are assembled together to obtain a stack in which these layers of semiconducting material alternate with the sheets.

21. (New) Process according to claim 20, wherein a first layer of semiconducting material is formed on each sheet, a thickness being less than a thickness of the layer of

semiconducting material, the group of tracks is formed on this first layer and a second layer of semiconducting material that covers these tracks is formed on the first layer, a total thickness of the first and second layers being equal to the thickness of the layer of semiconducting material.

22. (New) Process for manufacturing the detector according to claim 12, wherein a half layer of semiconducting material is deposited on two opposite faces of two successive sheets, and then the group of tracks is formed on one of the half layers and the sheets thus covered are assembled together to create a stack in which the layers alternate with the sheets.

#### IN THE ABSTRACT

Please delete the abstract on page 23 in its entirety and insert therefor:

#### ABSTRACT OF THE DISCLOSURE

A two-dimensional detector of ionizing radiation and a process for manufacturing the detector. The detector includes sheets emitting particles by interaction with ionizing radiation, semiconducting layers that alternate with the sheets and can be ionized by the particles, and groups of conducting tracks in contact with the layers. A created electric field is used to collect charge carriers generated in the layers due to interaction with particles, through the tracks. For example, the layer and the corresponding tracks are formed on each sheet and the sheets are then assembled together. The detector, as an example, is applicable to radiography and can achieve good X-ray detection efficiency and high spatial resolution at the same time.

Favorable consideration of this application, as presently amended, is respectfully requested.

The present Preliminary Amendment is submitted to place the above-identified application in more proper format under United States practice.

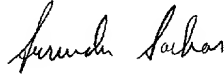
By the present Preliminary Amendment original Claims 1-11 are cancelled and new Claims 12-22 are presented for examination. New Claims 12-22 are deemed to be self-evident from the original disclosure, including original Claims 1-11, and thus are not deemed to raise any issues of new matter. The differences between new Claims 12-22 and original Claims 1-11 are deemed to at most broaden the scope of new Claims 12-22.

A new Abstract believed to be in more proper format under United States practice is also submitted herein.

The present application is believed to be in condition for a full and thorough examination on the merits. An early and favorable consideration of the present application is hereby respectfully requested.

Respectfully submitted,

OBLON, SPIVAK, McCLELLAND,  
MAIER & NEUSTADT, P.C.



Gregory J. Maier  
Attorney of Record  
Registration No. 25,599  
Surinder Sachar  
Registration No. 34,423



**22850**

(703) 413-3000  
Fax #: (703) 413-2220  
SNS/law

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<b>Marked-Up Copy</b>
Serial No:
Amendment Filed on:
10-15-01

IN THE CLAIMS

Claims 1-11 (Cancelled)

Claims 12-22 (New).

IN THE ABSTRACT

(New).

## DESCRIPTION

5

For example, the invention can be used to detect X  
10 photons, gamma photons, protons, neutrons and muons.

15

- experiments in detonics,
- fast non-destructive testing,
- position of patients in radiotherapy,
- high-energy physics,
- neutronography,        protonography,        radiography,  
  gammagraphy,
- surgery under radioscopy, and
- safety in airports

## STATE OF PRIOR ART

Two-dimensional detectors of ionizing radiation  
25 made of plates of a heavy metal such as lead or more  
generally a material capable of interaction with an  
incident ionizing radiation, are already known.

ENGLISH TRANSLATION OF THE AMENDED SHEETS OF INTERNATIONAL  
EXAMINATION REPORT

In particular, US S 117 114 A describes a radiation detector. In one example, the detector comprises a sequence of plane and parallel detection  
5 matrices. Each matrix comprises a set of amorphous silicon detection cells equipped with addressing electrodes and an adjacent layer made of a metallic conversion material such as Pb or U. This makes it possible to determine the energy and initial position  
10 of an X photon or a gamma photon that arrives at the first layer of metallic conversion material, perpendicular to this layer.

US 4 210 805 A describes a radiation detector. In one example, eight semiconductor elements 30 are laid  
15 out in the form of a matrix. Two opposite faces on each element are covered with conducting layers and the other two faces are covered with insulating layers that separate them from neighbouring elements.

20

For example, it is known how to use a metal with atomic number  $Z$  equal to or greater than 73 to detect X or gamma photons and a material with an atomic number  $Z$  usually less than 14 or greater than 90 to detect  
5 neutrons. Other materials such as gadolinium ( $Z = 64$ ) can also be used to detect neutrons.

The plates are perforated with holes by chemical or electrochemical etching and are electrically insulated from each other if necessary (when the  
10 required thickness of the plates is equal to 100 or more micrometers).

The holes are filled with an ionizable gas.

An incident high energy X or gamma photon then generates at least one photoelectron in one of the  
15 plates of the detector, by the Compton effect or by the pair creation effect.

This incident X or gamma photon communicates fast movements to this electron with a kinetic energy of the order of magnitude of the energy of the incident  
20 photon; this fast electron then ionizes some gas molecules contained in one of the holes into which the electron arrives, and that the electron usually passes through.

The slow secondary electrons that are torn off  
25 these molecules due to ionization of these molecules, are guided along this hole and collected using an electrical bias field, also called an electrical drift field, and are then detected, for example, in an ionization chamber or in a proportional avalanche  
30 chamber.

This type of two-dimensional detector is described in a number of documents including references [1], [2], [3], [4] and [5] mentioned at the end of this description.

A detection structure with holes is chosen because this type of structure is known to be very conducive to obtaining a good spatial resolution and a good efficiency, provided that the holes are perfectly  
5 formed and are sufficiently large.

These holes are formed by chemical etching; this method is preferred to water jet cutting which generates a front shock when the jet is opened, when starting to perforate a hole.

10 This front shock causes scaling of the material in which the holes are to be formed, which causes spalling of this material and makes it unsuitable for use.

But chemical etching is a slow and expensive technique.

15 Furthermore, the efficiency at which secondary electrons are collected and therefore the efficiency of these hole detectors are limited because this technique is used; only 10 to 30% of the secondary electrons created during each gas ionization are collected.

20 Chemical etching cannot be used to produce holes with sufficiently cylindrical walls because it generates narrow points in the holes that deform the electric field lines and reduce the useful diameter of the holes, with the result that the global efficiency  
25 of hole detectors is limited.

#### PRESENTATION OF THE INVENTION

The purpose of this invention is to overcome these  
30 disadvantages of high cost and limited efficiency.

More precisely, the purpose of this invention is a two-dimensional detector of incident ionizing radiation composed of first particles, this detector comprising a

stack of sheets of a first material capable of emitting second particles by interaction with the incident ionizing radiation, this detector being characterized in that it also comprises:

- 5       - layers of a semiconducting material that alternate with sheets of the first material and may be ionized by the second particles, each of the layers being associated with one of the sheets, the stack having first and second  
10       opposite faces each containing corresponding edges of sheets and layers, the detector being designed to be laid out such that the ionizing radiation arrives on the first face, the length of each sheet measured from the first face as  
15       far as the second face being equal to at least one tenth of the free average path of the first particles in the first material,
- groups of parallel and electrically conducting tracks extending from the first to the second  
20       face parallel to the layers, each group being associated with one of the layers and in contact with it, the tracks being designed to collect charge carriers that are generated in the layers by interaction of the layers with the second  
25       particles and possibly with the first particles and that are representative of the first particles in intensity and in position, and
- means of creating an electric field capable of causing collection of charge carriers through  
30       the tracks.

The detector according to the invention can be made at a much lower cost than the hole detectors mentioned above.

Furthermore, the collection efficiency and the spatial resolution of the detector according to the invention may be very much greater than the corresponding values for hole detectors.

5       According to a particular embodiment of the detector according to the invention, the first material is electrically conducting, the tracks are electrically insulated from the sheets and the means of creating the electric field comprise means of applying a voltage  
10       between the tracks and the sheets, this voltage being sufficient to cause the collection of charge carriers through the tracks.

Preferably, each group of tracks is fully located within the layer with which it is associated.

15       In this case, according to another particular embodiment, the first material is electrically conducting and the means of creating the electric field comprise means of applying a voltage between the tracks and the sheets, this voltage being sufficient to cause  
20       collection of charge carriers through the tracks.

According to another particular embodiment, the sheets are electrically insulating, an electrically conducting layer is inserted between each layer of semiconducting material and the sheet that is  
25       associated with it and the means of creating the electric field comprise means of applying a voltage between the tracks and the electrically conducting layers, this voltage being able to cause collection of charge carriers through the tracks.

30       The semiconducting material may be crystalline, ceramic, vitreous, amorphous or polymer.

It may be chosen among the group including thin layers of diamond, CdTe, ZnTe, CdZnTe, AsGa and

particularly  $\text{AsGaAl}_x\text{P}_{1-x}$  ( $0 < x < 1$ ), InP, InSb, SiC, crystalline silicon, amorphous silicon, organic crystals for example such as anthracene, naphthalene and PPV, amorphous selenium and chalcogenic glass  
5 ( $\text{As}_2\text{S}_3$ ).

The detector according to the invention may also comprise an electronic device for reading electrical signals output by tracks when the tracks collect charge carriers.

10 According to one preferred embodiment of the invention, one end of each track is curved to extend onto an edge of the corresponding layer of semiconducting material, this edge being located on the second face of the stack, and the device comprises  
15 electrically conducting pads that are in contact with the curved ends of the tracks respectively.

This invention also relates to a process for manufacturing the detector according to the invention.

According to this process, a layer of  
20 semiconducting material is formed on each sheet, this layer being provided with the group of tracks associated with it, and the sheets provided with layers of semiconducting material and tracks are assembled together to obtain a stack in which these layers of  
25 semiconducting material alternate with the sheets.

According to one particular embodiment of the process according to the invention, a first layer of semiconducting material is formed on each sheet, the thickness being less than the thickness of the said  
30 layer of semiconducting material, the group of tracks is formed on this first layer and a second layer of semiconducting material that covers these tracks is formed on the first layer, the total thickness of the



first and second layers being equal to the thickness of the said layer of semiconducting material.

It would also be possible to deposit a half layer of semiconducting material on the two opposite faces of two successive sheets, and then form the group of tracks on one of the half layers and assemble the sheets thus covered to create a stack in which the layers alternate with the sheets.

## 10 BRIEF DESCRIPTION OF THE DRAWINGS

This invention will be better understood after reading the description of example embodiments given below, for guidance only and in no way restrictive, with reference to the attached drawings on which:

- Figure 1 is a perspective diagrammatic view of a particular embodiment of the detector according to the invention,
- figure 2 is a diagrammatic cross-sectional view of the detector in figure 1 along plane P on figure 1,
- figure 3 is a diagrammatic sectional perspective view of another detector according to the invention, and
- figure 4 is a diagrammatic and partial perspective view of another detector according to the invention.

## DETAILED PRESENTATION OF PARTICULAR EMBODIMENTS

30

A detector of ionizing radiation according to the invention is diagrammatically shown in perspective on

figure 1 and in a cross-section along a plane P on figure 2.

In the example shown, the ionizing radiation is composed of X photons, that may for example have an energy of 5 MeV.

The detector in figures 1 and 2 comprises a stack 2 of sheets 4 of an electrically conducting material that can emit electrons by interaction with X photons in incident ionizing radiation.

This detector also comprises layers 6 of a semiconducting material that alternate with sheets 4 and can be ionized by the photo-electrons emitted by the conducting material when this material interacts with X photons and possibly directly by primary X photons, although to a lesser extent.

Each of the layers 6 is associated with one of the sheets 4.

The stack of sheets 4 and layers 6 has a first face 8 and a second face 10 that are opposite to each other.

Each face 9 and 10 contains edges 12 of sheets 4 and edges 14 of layers 6 that alternate with the edges 12 of sheets 4.

The detector in figures 1 and 2 is oriented such that the ionizing radiation to be detected arrives on face 8.

The length of each sheet 4, starting from face 8 and as far as face 10, is equal to at least one tenth of the average free path of X photons in the conducting material from which the sheets 4 are made.

As can be seen on figures 1 and 2, an incident X photon, with the trajectory as shown as reference 16 on figures 1 and 2, interacts with the conducting material

in sheet 4 to produce a high kinetic energy electron with the trajectory shown by arrow 18 on figure 2, due to the Compton, photoelectric or pair creation effect.

Figure 2 also contains an arrow 20 that shows the trajectory of a photon with less energy than the energy of the incident X photon resulting from interaction of this photon with the conducting material of sheet 4.

The detector in figures 1 and 2 also comprises groups of parallel electrically conducting tracks 22 that extend from face 8 as far as face 10 parallel to layers 6.

Each group of tracks 22 is associated with one of the layers 6 and is in contact with it.

Tracks 22 are intended to collect charge carriers that are generated in layers 6 by interaction between these layers and the electrons resulting from the interaction of X photons incident with the conducting material from which the sheets 4 are made.

These charge carriers are representative of the intensity and position of incident X photons.

Figure 2 shows a charge carrier with a trajectory shown as reference 24 and that results from interaction of the electron with trajectory 18 with a layer 6, and this charge carrier with trajectory 24 is collected by a conducting track 22 associated with this layer 6.

The detector also includes means 26 (figure 1) of creating an electric field capable of causing collection of charge carriers through the tracks 22.

For guidance only and in no way restrictively, the detector in figures 1 and 2 is laid out such that sheets 4 and layers 6 are horizontal or vertical, but other orientations are possible depending on the use to be made of the detector.

All that is necessary is that the sheets 4 and layers 6 should be approximately parallel to the direction of the ionizing radiation to be detected.

In the example shown in figures 1 and 2, each group of conducting tracks 22 is contained in the layer 6 with which this group is associated.

This avoids the need to use electrically insulating supports (for example made of plastic or ceramic) for the tracks, these supports being cumbersome which reduces the spatial resolution of the detector, and which in any case are useless for the detection itself.

In the case shown on these figures 1 and 2, the means 26 of creating the electric field are means of applying a voltage between tracks 22 and sheets 4, this voltage being able to cause collection of charge carriers through the tracks 22.

Note that the cut plane P (figure 2) passes through the conducting tracks in the same row of tracks (horizontal row on figure 1), the tracks on this row belonging to layers 6 respectively.

In a particular embodiment not shown, the material from which the sheets 4 are made is also electrically conducting but the tracks 22 are no longer contained in layers 6 of semiconducting material; each group of tracks is at the interface with the corresponding layer of semiconducting material and the sheet of conducting material that is associated with an adjacent layer of semiconducting material.

In this case, an electrically insulating material is provided to electrically insulate the tracks 22 from the sheets 4 of conducting material, but it would also

be possible to use the same means of creating the electric field as above.

The detector in figures 1 and 2 is provided with an electronic device 30 for reading electric signals supplied by tracks 22 when they collect charge carriers.

Figure 2 clearly shows that one end 32 of each track 22 is curved so that it passes along an edge 14 of the corresponding layer 6, this edge being located on the face 10 of the stack of sheets 4 and layers 6.

The electronic reading device 30 comprises electrically conducting pads 34 that are shown in contact with the curved ends 32 of tracks 22.

This contact may be made using brazing balls 36, for example indium balls, or by means of electrically conducting wires or even using appropriate means to bring the curved ends of the tracks into contact with the pads of the associated reading device, for example by pressing or with an electrically conducting glue.

Note that the pads 34 are laid out at the same pitch as the curved ends 32 of the tracks 22.

An undoped semiconducting material can be used, or alternatively a doped semiconducting material may be used, for example an N type material in which case the electrons are the majority charge carriers, or a P type material in which case holes will be the majority carriers.

A negative voltage can be applied to the conducting sheets 4 and the conducting pads 34 (and therefore tracks 22) can be grounded, or sheets 4 can be grounded and a positive potential can be applied to conducting pads 34 and therefore tracks 22 in order to collect charge carriers.

In both cases, the holes generated in the layers 6 of semiconducting material are attracted by the sheets 4 of conducting material, whereas the electrons generated in these layers 6 are attracted and collected by the tracks 22, thus supplying electrical signals that are read using device 30.

Conversely, a positive potential can be applied to sheets 4 and pads 34 can be grounded or sheets 4 can be grounded and a negative potential can be applied to pads 34. In both cases, electrons are attracted by the sheets and holes are attracted and collected by the tracks, thus providing even more electrical signals that are read using device 30.

In each case, the tracks 22 convert the analog image transported by the X rays that are detected into digital and electrical form.

In the example shown on figure 2, all tracks 22 are grounded through electrically conducting pads 34 and a negative potential is applied to all sheets of conducting material 4 by means of a voltage source 38.

In this case, the tracks 22 collect electrons.

A negative potential (for example equal to -500 V) can be applied to all sheets 4 of conducting material using an electrically insulating plate 40 on one face of which electrically conducting parallel tracks 42 are formed at a pitch equal to the pitch of the sheets 4.

All these tracks 42 are connected to a track 44 also formed on this face of the plate 40 and this track 44 is connected to the negative voltage source 38.

The face of the plate 40 on which the tracks 42 are located is then applied in contact with a face of the stack 2 on which the edges of the sheets 4 also appear, this face being different from faces 8 and 10,

such that the tracks 42 come into contact with the edges of the corresponding sheets 4, which means that all these sheets 4 can be brought to the required negative potential.

5       For example, plate 40 is a ceramic or polymer plate and tracks 42 and 44 may be made of gold.

Preferably, for reasons of size and reading speed, the electronic reading device 30 is of the type used in the CCD sensors.

10       For a detector with modest dimensions, the tracks 22 of the stack 2 can be directly connected to the pixels of a CCD sensor without a coating.

For a detector with larger dimensions, an intermediate connection matrix may be used between tracks 22 of the stack 2 and the reading device, for example of the CCD type.

15       The conducting pads 34 are then located on one of the faces of this matrix so that they can be connected to the curved ends 32 of the tracks 22, and these pads are electrically connected to the pixels of a reading device, for example of the CCD type, through electrical connections that pass through this matrix.

20       The thickness of a detector according to the invention, for example like the detector in figure 1, measured from face 8 as far as face 10, may be of the same order of magnitude as the thickness of a holes detector of the type described above, this thickness being adapted as a function of the required stopping power.

25       Note that the material from which sheets 4 are made may be chemically inert or it may be a bad conductor of electricity (a case in which it is insulating will be considered later), unlike the

electrochemically machinable material that must be used for hole detectors.

The thicknesses of sheets 4 of conducting material (or insulating material as will be seen later) and layers 6 of semiconducting material are fixed to optimize the spatial resolution of the detector and the conversion efficiency (conversion and collection of charges). Preferably, the smallest possible thicknesses will be used, typically of the order of 100  $\mu\text{m}$  to a few hundreds of micrometers.

For example, it would be possible to use sheets 4 of conducting material with a thickness of the order of 200  $\mu\text{m}$  and layers 6 of a semiconducting material with a thickness of the order of 200  $\mu\text{m}$ .

Note that in hole detectors according to prior art, the thickness of metal sheets measured perpendicular to the direction of the incident radiation, is fixed such that these sheets may be chemically etched (thickness of the order of 200  $\mu\text{m}$ ).

In this invention, this constraint is inapplicable, and the thickness of the sheets 4 of material (conducting or insulating) and layers 6 of the semiconducting material is defined entirely by application constraints.

Note also that the structure of a detector according to the invention can induce spectacular improvements to the efficiency (of the order of 50%) with an appropriate thickness of material along the direction of the radiation to be detected, and the spatial resolution that may be of the order of 100  $\mu\text{m}$  by choosing a pitch that is appropriate for tracks 22.

The spatial resolution in the direction perpendicular to the sheets 4 is determined by the



pitch between the sheets 4 and between the tracks (that may be of the order of 50  $\mu\text{m}$  to 200  $\mu\text{m}$ ).

X-rays are detected preferably using heavy metal, for example tungsten or lead.

5 For guidance, and in no way restrictively, for a case in which X photons with an energy equal to 5 MeV are to be detected, a 2 cm thick detector could be used (measured from face 8 as far as face 10 in figure 1), 100  $\mu\text{m}$  thick layers 6 made of CdTe or diamond and 400  $\mu\text{m}$  thick sheets 4 made of tungsten with tracks 22 at a pitch of 0.5 mm. These dimensions could be reduced if necessary, since a pitch of 100 mm would be technologically feasible.

We will now describe an example process for 15 manufacturing the detector shown in figures 1 and 2.

The sheets 4 of conducting material may be made using any process.

Their surface must be sufficiently conducting and must not be oxidized.

20 This surface may be coated, if necessary, by a metallic deposit more suitable for making a resistive contact with the semiconducting material, for example a layer of gold.

The following procedure may be used to form the 25 tracks 22 that may be made of gold or a metal better adapted to the semiconductor used, on the layers 6 of semiconducting material:

30 - a first thickness (for example 50  $\mu\text{m}$ ) of semiconducting material is deposited on one of the faces on one of the conducting sheets 4, for example by chemical vapor deposition, by epitaxy, by pouring in strips, by liquid phase deposition or by a sol-gel deposition),

- the gold tracks 22, for example 5  $\mu\text{m}$  wide, are deposited by evaporation through a mask or by a photolithography process, onto the semiconducting material thus deposited, and
- 5 - a second thickness of semiconducting material is deposited on the first thickness in order to cover the tracks 22 and to obtain the required total thickness of semiconducting material (for example 100  $\mu\text{m}$ ).

10 The same process is used for each conducting sheet 4.

As a variant, it would also be possible to deposit a half-layer of semiconducting material on each opposite side of two successive sheets, and then form  
15 the group of tracks on one of the half-layers.

The conducting sheets 4 thus covered are then stacked to obtain an alternation of conducting sheets 4 and semiconducting material layers 6 and are held in contact with each other by applying slight pressure  
20 exerted by appropriate means, for example a mechanical device or an electrically conducting glue.

The detector according to the invention that is diagrammatically shown in a sectional perspective view on figure 3, is different from than in figure 1 due to  
25 the fact that the sheets 4 are electrically insulating, for example made of plastic in the case shown in figure 3, for example in order to detect neutrons, and by the fact that a thin electrically conducting layer 46 (thickness of the order of 5  $\mu\text{m}$  to 10  $\mu\text{m}$ ) for example  
30 made of gold or copper as shown on figure 3, is inserted between each sheet 4 of insulating material and the corresponding layer of semiconducting material.

In this case, the required electrical potential with respect to the tracks 22 can be applied to all electrically conducting layers 46 through electrically conducting tracks such as the tracks 42 formed on the insulating plate 40 (Figure 1).

Figure 4 is a diagrammatic and partial perspective view of a variant embodiment of the detector in figure 1.

In the detector in figure 4, each layer 6 is a layer of adjacent wires 6a made of semiconducting material, each wire containing a metallic strand forming a track 22 along its centerline.

The wires 6a provided with these tracks 22 can be made by extrusion or drawing.

The following documents are referenced in this description:

- [1] V. Perez-Mendez, S.I. Parker, IEEE Trans. Nucl. Sci. NS-21 (1974) 45
- [2] S.N. Kaplan, L. Kaufman, V. Perez-Mendez, K. Valentine, Nuclear Instruments and Methods 106 (1973) 397
- [3] A.P. Jeavons, G. Charpak, R.J. Stubbs, NIM 124 (1975) 491-503
- [4] Jean-Louis Gerstenmayer, Damien Lebrun and Claude Hennion, "Multistep parallel plate avalanche chamber as a 2D imager for MeV pulsed radiography", Proc. SPIE, vol. 2859, p. 107 to 114, August 7 to 9 conference, 1996, Denver, Colorado, USA
- [5] J.L. Gerstenmayer, "High DQE performance X- and Gamma-ray fast imagers: emergent

B 13195.3 PV

CLAIMS

1. Two-dimensional detector of incident ionizing  
5 radiation composed of first particles, this detector  
comprising a stack (2) of sheets (4) of a first  
material capable of emitting second particles by  
interaction with the incident ionizing radiation, this  
detector being characterized in that it also comprises:
- 10 - layers (6) of a semiconducting material that  
alternate with sheets of the first material and  
may be ionized by the second particles, each of  
the layers being associated with one of the  
sheets, the stack having opposite first (8) and  
15 second (10) faces each containing corresponding  
edges (12, 14) of sheets and layers, the  
detector being designed to be laid out such that  
the ionizing radiation arrives on the first face  
(8), the length of each sheet measured from the  
20 first as far as the second face being equal to  
at least one tenth of the free average path of  
the first particles in the first material,
- groups of parallel and electrically conducting  
tracks (22) extending from the first to the  
25 second face parallel to the layers (6), each  
group being associated with one of the layers  
and in contact with it, the tracks being  
designed to collect charge carriers that are  
generated in the layers by interaction of the  
30 layers with the second particles and possibly  
with the first particles and that are  
representative of the first particles in  
intensity and in position, and

- means (26) of creating an electric field capable of causing collection of charge carriers through the tracks (22).

2. Detector according to claim 1, in which the  
5 first material is electrically conducting, the tracks (22) are electrically insulated from the sheets and the means of creating the electric field comprise means (26) of applying a voltage between the tracks (22) and the sheets (4), this voltage able to cause collection  
10 of charge carriers through the tracks.

3. Detector according to claim 1, in which each group of tracks (22) is fully located within the layer (6) with which it is associated.

4. Detector according to claim 3, in which the  
15 first material is electrically conducting and the means of creating the electric field comprise means (26) of applying a voltage between the tracks (22) and the sheets (4), this voltage able to cause collection of charge carriers through the tracks.

20 5. Detector according to either of claims 1 or 3, in which the sheets (4) are electrically insulating, an electrically conducting layer (46) is inserted between each layer (6) of semiconducting material and the sheet (4) that is associated with it and the means of  
25 creating the electric field comprise means (26) of applying a voltage between the tracks (22) and the electrically conducting layers (46), this voltage able to cause collection of charge carriers through the tracks.

30 6. Detector according to any one of claims 1 or 5, in which the semiconducting material may be chosen among the group including thin layers of diamond, CdTe, ZnTe, CdZnTe, AsGa and their alloys, InP, InSb, SiC,

crystalline silicon, amorphous silicon, organic crystals, amorphous selenium and chalcogenic glass ( $\text{As}_2\text{S}_3$ ).

7. Detector according to any one of claims 1 to 5 6, also comprising an electronic device (30) for reading electrical signals output by tracks (22) when the tracks collect charge carriers.

8. Detector according to claim 7, in which one end (32) of each track is curved to extend onto an edge (14) of the corresponding layer (6) of semiconducting material, this edge being located on the second face (10) of the stack (2), and the device (30) comprises electrically conducting pads (34) that are in contact with the corresponding curved ends (32) of the tracks 15 (22).

9. Process for manufacturing the detector according to any one of claims 1 to 8, in which a layer (6) of semiconducting material is formed on each sheet (4), this layer being provided with the group of tracks 20 (22) associated with it, and the sheets provided with layers of semiconducting material and tracks are assembled together to obtain a stack (2) in which these layers of semiconducting material alternate with the sheets (22).

25 10. Process according to claim 9, in which a first layer of semiconducting material is formed on each sheet (4), the thickness being less than the thickness of the said layer (6) of semiconducting material, the group of tracks (22) is formed on this first layer and 30 a second layer of semiconducting material that covers these tracks is formed on the first layer, the total thickness of the first and second layers being equal to

1

5  
10

[illegible]



1/3

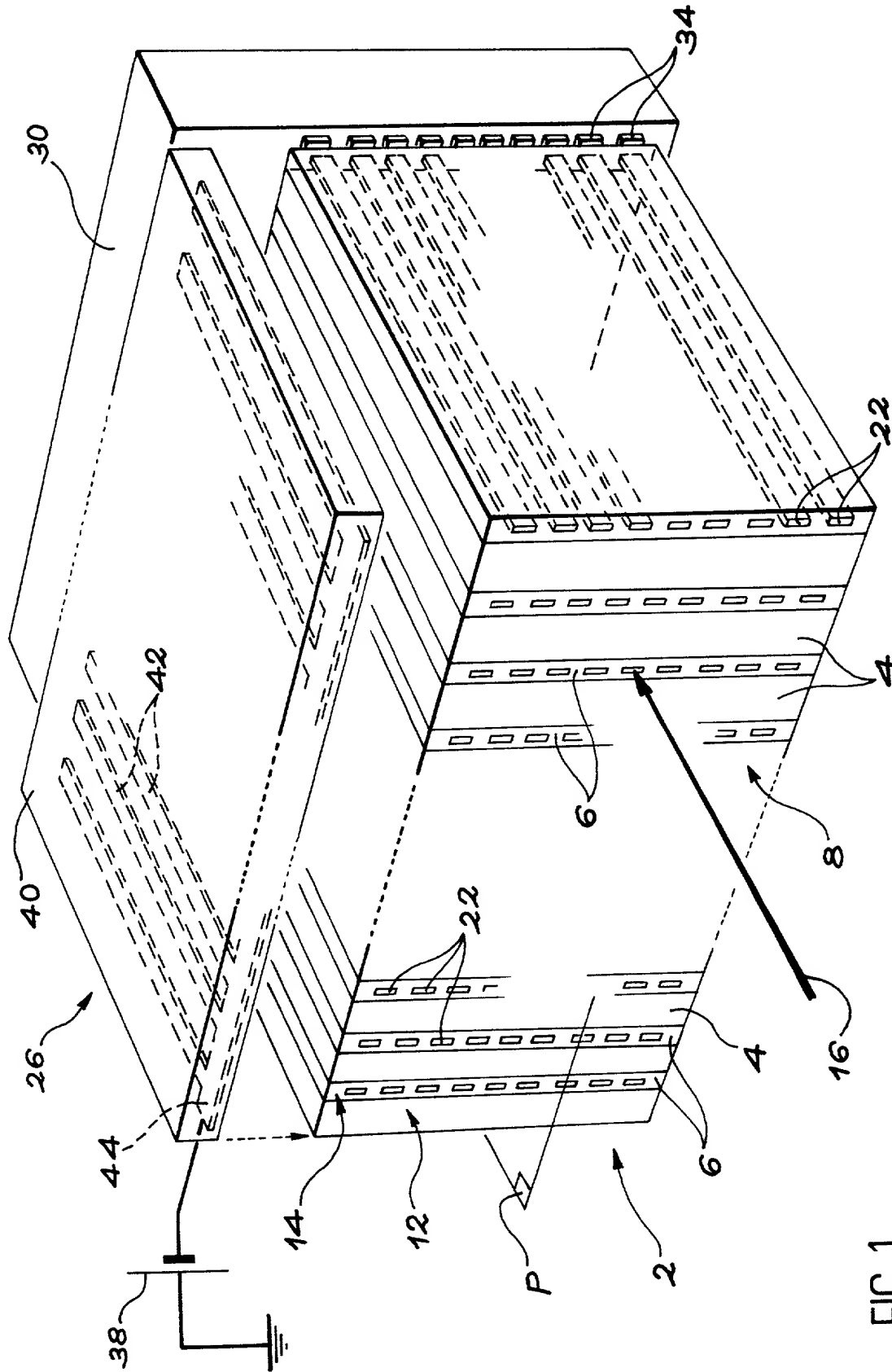


FIG. 1

FIG. 1

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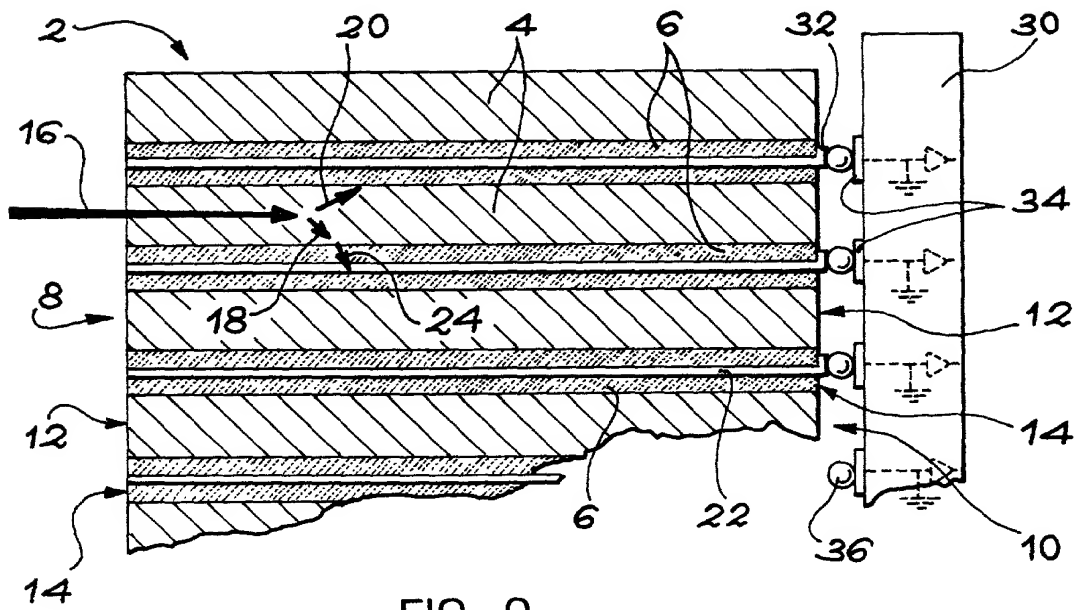
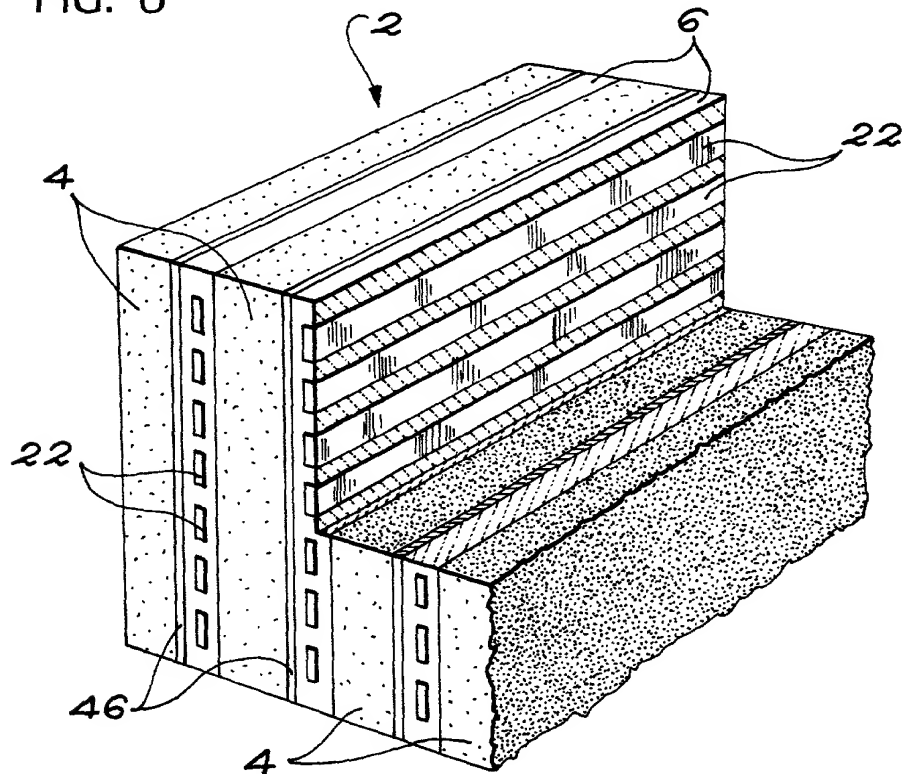


FIG. 2

FIG. 3



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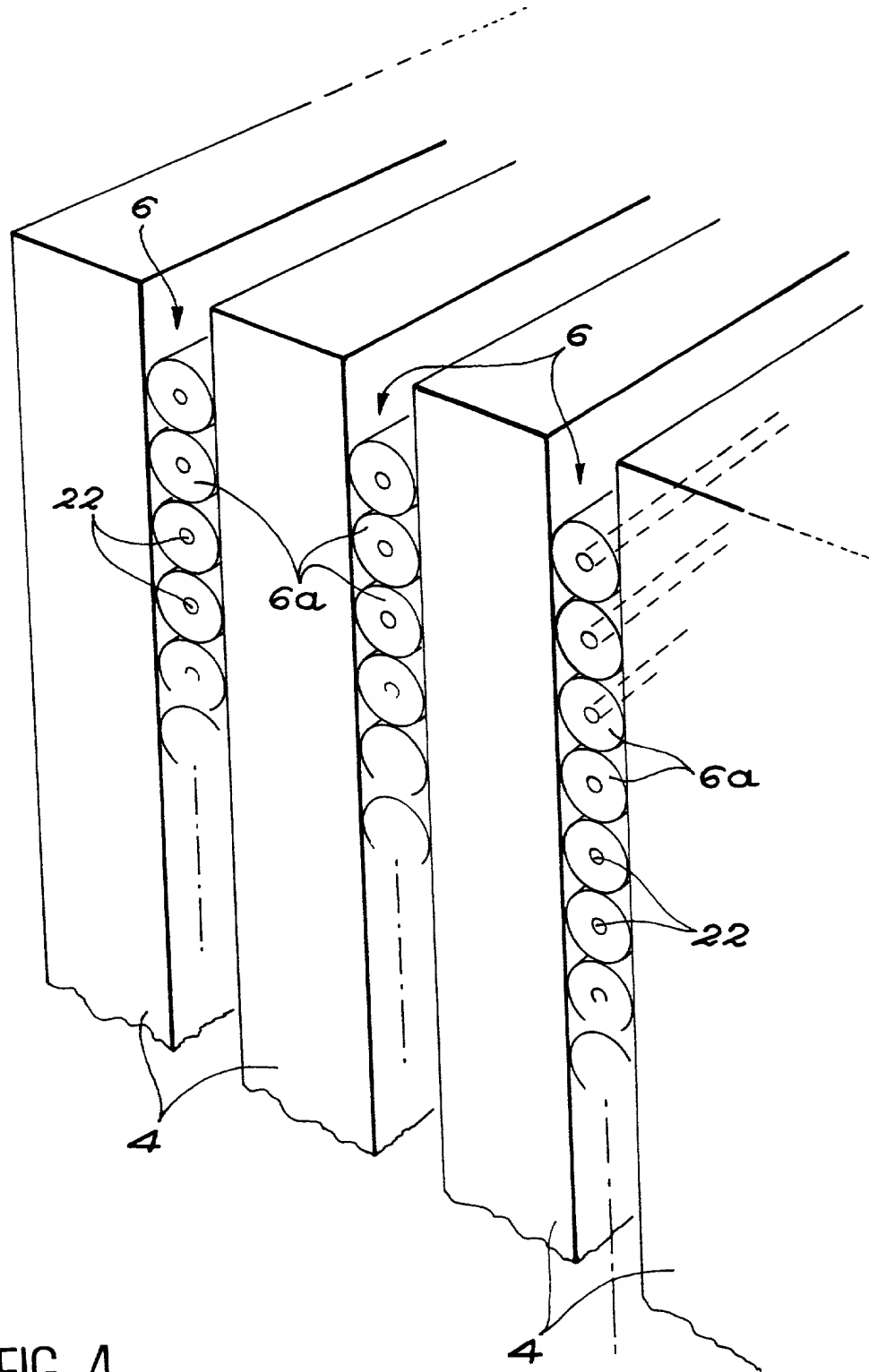


FIG. 4

*Declaration, Power Of Attorney and Petition*

WE (I) the undersigned inventor(s), hereby declare(s) that :

My residence, post office address and citizenship are as stated below next to my name,

We (I) believe that we are (I am) the original, first, and joint (sole) inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention entitled

TWO-DIMENSIONAL DETECTOR OF IONIZING RADIATION AND PROCESS FOR MANUFACTURING THIS DETECTOR

the specification of which

- ☐ is attached hereto.
- ☐ was filed on  
as Application Serial No.  
and amended on
- ☒ was filed as PCT international application  
Number PCT/FR00/00917 ✓  
on April 11, 2000 ✓  
and was amended under PCT Article 19  
on March 08, 2001

We (I) hereby state that we (I) have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

We (I) acknowledge the duty to disclose information known to be material to the patentability of this application as defined in Section 1.56 of Title 37 Code of Federal Regulations.

We (I) hereby claim foreign priority benefits under 35 U.S.C. § 119 (a)-(d) or § 365 (b) of any foreign application(s) for patent or inventor's certificate, or § 365 (a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed. Prior Foreign Application (s)

Application No.	Country	Day/month/Year	Priority Claimed	
99 04725 ✓	FRANCE	15 APRIL 1999 ✓	<input checked="" type="checkbox"/> YES	<input type="checkbox"/> NO
_____	_____	_____	<input type="checkbox"/> YES	<input type="checkbox"/> NO
_____	_____	_____	<input type="checkbox"/> YES	<input type="checkbox"/> NO
_____	_____	_____	<input type="checkbox"/> YES	<input type="checkbox"/> NO

We (I) hereby claim the benefit under Title 35, United States Code, § 119 (e) of any United States provisional application(s) listed below.

(Application Number)

(Filing Date)

(Application Number)

(Filing Date)

We (I) hereby claim the benefit under 35 U.S.C. §120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of prior application and the national or PCT International filing date of this application.

Application Serial No.

Filing Date

Status (pending, patented,  
abandoned)

21 09926328 "01501" FOSTON 82292660

And we (I) hereby appoint : Norman F. Oblon, Registration Number 24,618; Marvin J. Spivak, Registration Number 24,913; C. Irvin McClelland, Registration Number 21,214; Gregory J. Maier, Registration Number 25,599; Arthur I. Neustadt, Registration Number 24,854; Richard D. Kelly, Registration Number 27,757; James D. Hamilton, Registration Number 28,421; Eckhard H. Kuesters, Registration Number 28,870; Robert T. Pous, Registration Number 29,099; Charles L. Gholz, Registration Number 26,395; Vincent J. Sunderdick, Registration Number 29,004; William E. Beaumont, Registration Number 30,996; Steven B. Kelber, Registration Number 30,073; Robert F. Gnuse, Registration Number 27,295; Jean-Paul Lavalleye, Registration Number 31,451; William B. Walker, Registration Number 22,498; Timothy R. Schwartz, Registration Number 32,171; Stephen G. Baxter, Registration Number 32,884; Martin M. Zoltick, Registration Number 35,745; Robert W. Hahl, Registration Number 33,893; and Richard L. Treanor, Registration Number 36,379; our (my) attorneys, with full powers of substitution and revocation, to prosecute this application and to transact all business in the Patent Office connected therewith; and we (I) hereby request that all correspondence regarding this application be sent to the firm of OBLON, SPIVAK, MCCLELLAND, MAIER & NEUSTADT, P.C., whose post Office Address is : Fourth Floor, 1755 Jefferson Davis Highway, Arlington, Virginia 22202.

We (I) declare that all statements made herein of our (my) own knowledge are true and that all statements made on information and belief are believed to be true ; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such wilful false statements may jeopardise the validity of the application or any patent issuing thereon.

1-87 GERSTENMAYER Jean-Louis

NAME OF FIRST SOLE INVENTOR

Signature of Inventor

Date

September 28, 2001

Residence : 35 bis rue des  
trois fermes, 91400, Orsay FR  
FRANCE

Citizen of :

France

Post Office Address : The same as residence